A Continuously Sensitive Cloud Chamber

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Abstract

In this report, we will discuss the construction and operation of a continuously sensitive cloud chamber and its applications towards studying cosmic rays and as a scientific exhibit. A continuously sensitive cloud chamber consists of a liquid of low vapor pressure in a steep temperature gradient. We used the vapor ethanol. Within this gradient the vapor forms a supersaturated layer. This layer is highly vulnerable to irregularities that trigger nucleation. These irregularities may come in the form of dust particles, mechanical pressure variations, or more specifically for our purpose, cosmic rays. A systematic study was made of the various parameters that influenced the operation of the cloud chamber and our ability to observe cosmic rays. We also survey past and recent experiments that employ cloud chambers.

Introduction

The continuously sensitive cloud chamber can detect particles from cosmic rays and radioactive sources. We have gathered data to be used in the construction of a science exhibit using a cloud chamber. This exhibit will allow children of all ages to observe the many otherwise invisible particles that pass through us everyday. People will be able to see the paths these particles take in the cloud chamber.

By working with two cloud chambers we have been able to compare and contrast what are the optimum conditions for operating a continuously sensitive cloud chamber when using the vapor ethanol. The two chambers will be identified as the small cloud chamber and the other as the large cloud chamber. In general we have experienced fewer problems when operating the small cloud chamber than with the large one, for various reasons.

Information of what cosmic rays are and how they were first discovered is presented, along with a discussion of the history of the cloud chamber and important discoveries made using it. Also, a clear idea of what our cloud chamber looks like and how it works is included. The size of our supersaturation layer and how we were able to achieve it is important in operating the cloud chamber. By comparing our temperature gradient with Alexander Langsdorf's data [1] we have better understood our own research.

History

The history of the cloud chamber and how it was made dates back to 1895. In that year C.T.R. Wilson built the cloud chamber in hopes of studying cloud formations, but then realized there was something more worthy of investigation [2]. Later (in 1927) he won the Nobel Prize for his invention. Other versions of the continuously sensitive cloud chamber have been invented since that time. Alexander Langsdorf invented the diffusion cloud chamber in late 1936; the data he collected for his cloud chamber proved to be very useful in our research [1].

There have been many important discoveries made using cloud chambers. The scientist C.D. Anderson first detected antimatter in 1933 using a cloud chamber; the particle was a positron [3]. The study of particles and cosmic rays has proved to be an important area of research. On an ironic note, the scientists Dr. Henri Svensmark, Dr. Friis-Christenseng and Dr. Knud Lassen, who are from the Danish Meteorological Institute in Copenhagen, are studying cosmic rays to see how they affect cloud formations [4]. Perhaps C.T.R. Wilson's invention will study cloud formation after all.

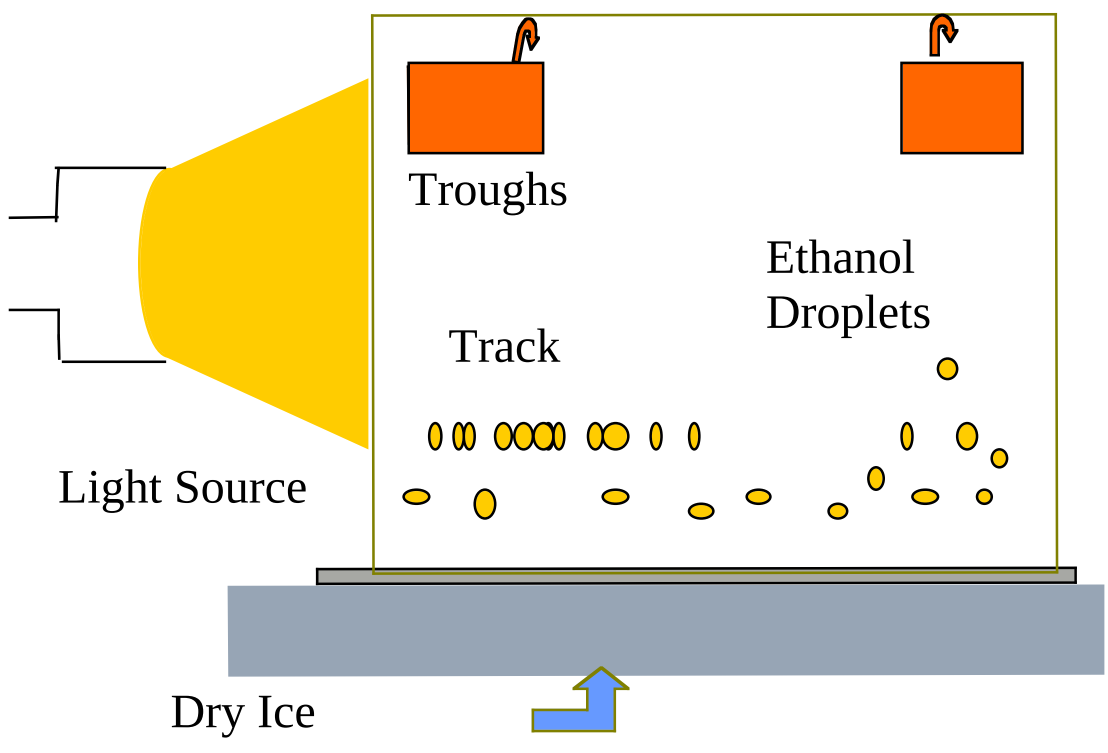

Figure 1. The large cloud chamber. Note: The dry ice and ethanol are stored in the gray area.

Apparatus

The large chamber (Fig. 1) consists of a 51 cm x 25 cm x 25 cm aquarium. Within the aquarium there are two troughs filled with ethanol, situated 10 cm from the bottom. The ethanol is fed to the troughs by two tubes. These tubes run through the ceiling of the chamber to two bulbs, which pump ethanol from two containers. Beneath the aquarium is a 61 cm x 36 cm x 0.64 cm aluminum plate attached to two aluminum rods (for good thermal contact with the base). Beneath the plate is a styrofoam base. The base consists of styrofoam surrounding a 51 cm x 25 cm x 5 cm aluminum pan. Crushed dry ice and ethanol are placed in the pan, which has a temperature of -67 degrees Celsius. The temperature of the dry ice is about -72 degrees Celsius.

The small chamber (Fig. 2) consists of a 20 cm x 13 cm x 13 cm plastic container, with two sponges placed along the sides of the top of the chamber. The sponges are soaked with ethanol. Below the plastic container is an aluminum plate to which vertical rods are attached. These rods are placed within a base made of styrofoam, with plastic in the center. Dry ice and ethanol are then placed within the base.

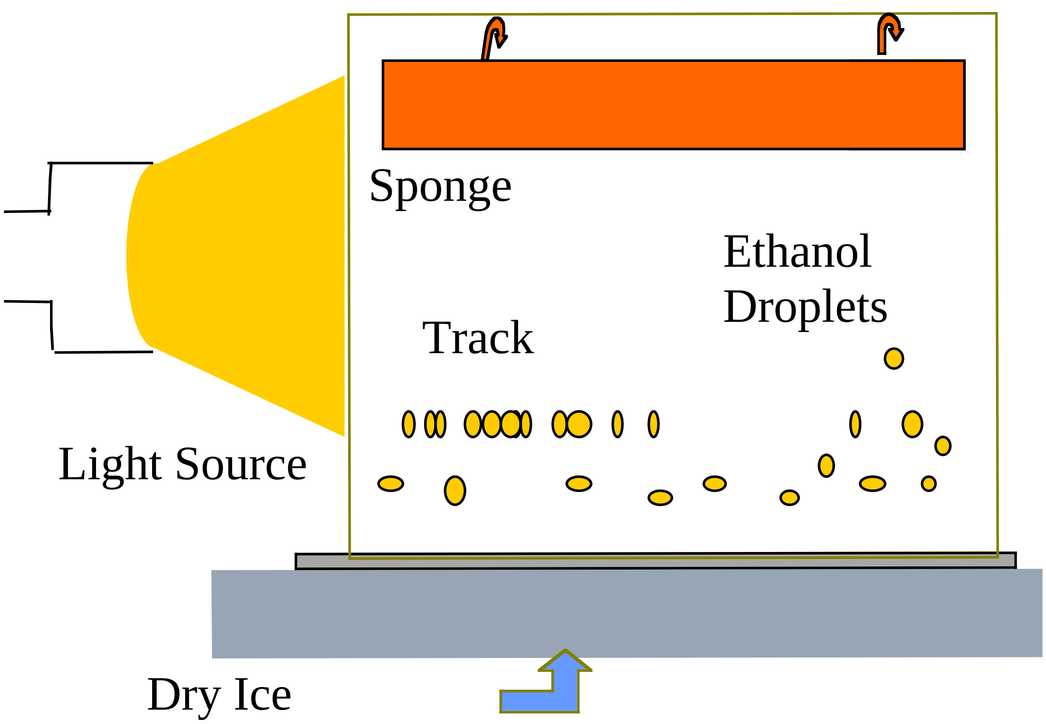

Figure 2. Layout of the small chamber. Note: The dry ice and ethanol are stored in the gray area.

In both chamber bases, ethanol was used for its various properties. The ethanol does not freeze, it allows good thermal contact with the plate, and it is less harmful and expensive than other substances that could have been used.

The principle of the experiment is to form a supersaturated layer of a volatile vapor in an enclosed volume, which will readily nucleate when cosmic rays travel through them. The chamber operation depends on a steep temperature gradient. The large chamber has 10 degrees Celsius at the top and -62 degrees Celsius at the bottom, forming a steep temperature gradient. This has systematically shown to render the optimum level of track observation in our large cloud chamber.

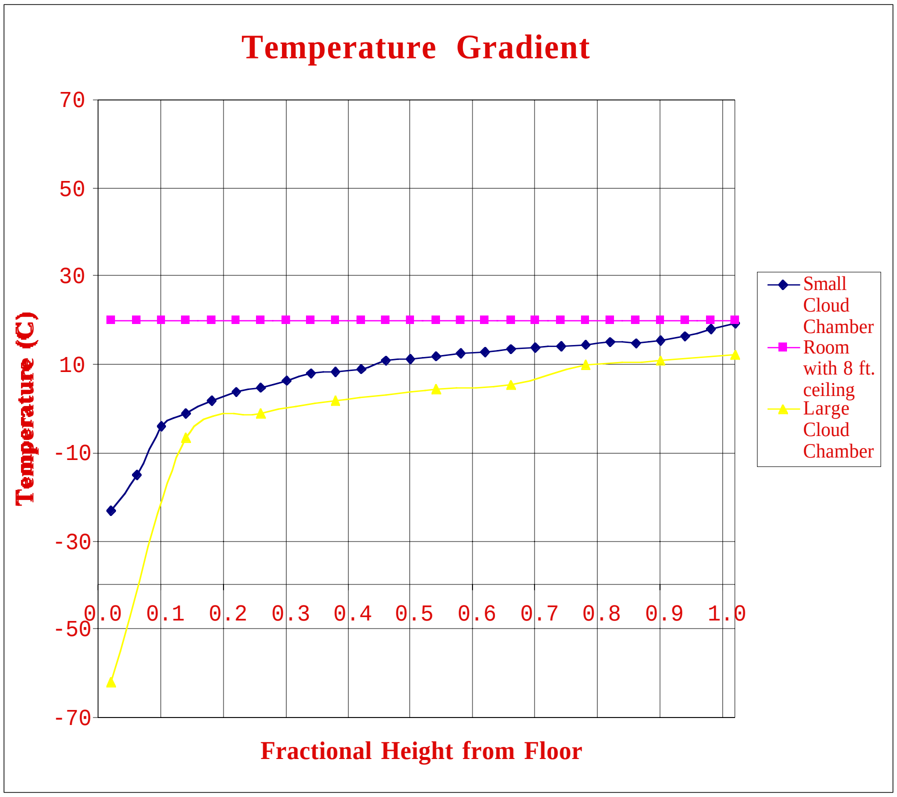

Figure 3. Temperature gradient of the small chamber, large chamber, and the room that the chamber was placed in. The steep change in temperature of the large chamber allows a 4 cm supersaturated layer.

This temperature gradient has been compared to other papers, and graphically displayed to match the other experiments (Fig. 3). The temperature gradient is the 52 degree Celsius change over 1/10 of the chamber which exceeds Langsdorf's gradient (Fig. 4). (Note: Langsdorf used an apparatus for heating the top of his chamber, while the top of our chamber was at room temperature). The low negative temperature at the bottom of the chamber is attained through good thermal contact: the aluminum rods being attached to the aluminum plate and immersed in dry ice and ethanol. This gradient allows supersaturation to reach 4 cm above the bottom of the large chamber. The bottom of the small chamber, with a more shallow temperature gradient, has a supersaturation layer of 2 cm (Fig. 3).

Analysis

This great thermal contact allowed our ethanol vapor in the chamber to be supersaturated, by supercooling the vapor. Within this supersaturated level various cosmic rays can be viewed passing through the chamber. This process allows us to view muons. Most cosmic rays that enter our cloud chamber enter vertically, and are too short to be seen due to the 4 cm depth of our sensitive layer of supersaturation. Therefore, the tracks that we can see are generally either scattered off an object or air molecules.

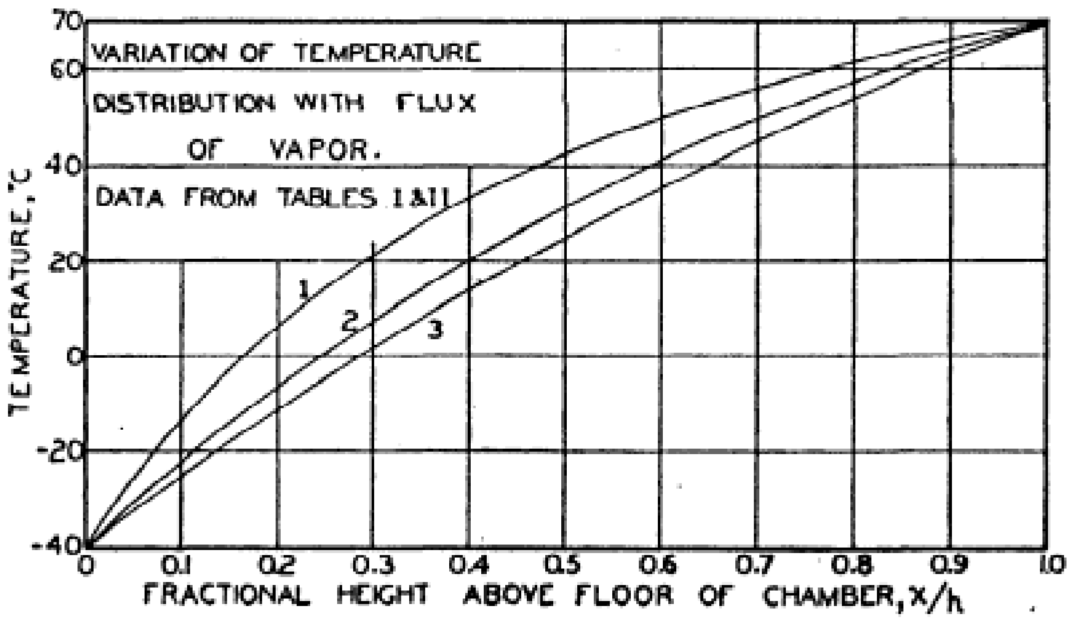

FIG. 3.

Figure 4. Temperature gradients that A. Langsdorf created and saw tracks with.

Supersaturation is when a substance is more concentrated than in normal saturation. In the case of our chamber, when the vapor falls from the top it leaves a warmer area and enters a much colder area of the chamber. The laws of temperature and pressure say this vapor should become a liquid. It does not become a liquid because something needs to trigger the nucleation. This is when we say the vapor is super saturated because it has a higher concentration of vapor than should be allowed.

How steep the temperature gradient determines how supersaturated our vapor will be. The temperature gradient describes the temperature as a function of height. For our cloud chambers we have an extreme change in temperature from the top to the bottom, which is what we want. Table I gives data we have collected for the two chambers.

Table I. The temperature gradients of the two chambers, the temperature differences from the top of the chamber to the bottom, when observing tracks.

Chamber	Temperature Difference	Distance (from the top to the bottom)
Large	-72 Degrees Celsius	15.5 cm
Small	-43 Degrees Celsius	12 cm

The process of various decays of sub nuclear-particles can be seen by the nucleation of the supersaturated layer. Nucleation occurs when the charged particle passes through the chamber and ionizes the supersaturation layer; this is when we see a track. A track is a collection of droplets that form right along the ionized path made by the charged particle.

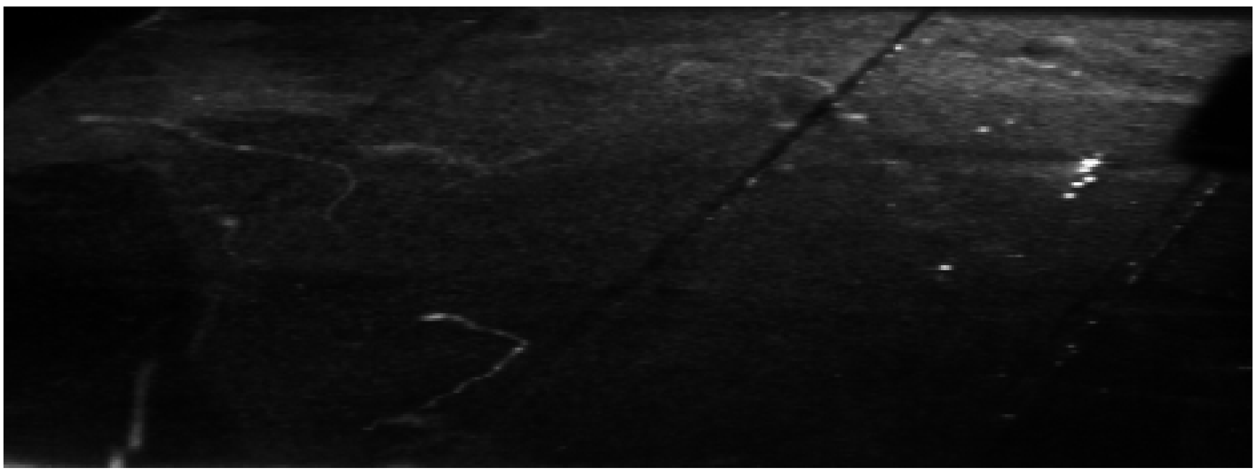

Figure 5. Picture of our large chamber. Note the track in the bottom left of the picture, there is a muon decay.

Through observation and analysis of our large chamber, we have viewed distinct types of tracks. We can find information about the particle by looking at its track. There is a relationship of the shape of the track to its energy. If we can tell how bent and twisted the track was then we can qualitatively compare how fast these particles are moving compared with other observed tracks. If we see a particle with a straight track (not shown) this indicates that the particle is moving fast. In Fig. 5 we see a slow moving particle with a twisted and bent path. This particle did not have as much energy as a particle with the straight path. Brightness is also affected by the energy of a track. The brighter the track, the less energy the track has. This can be seen in the Fig. 6. Consequently, the air molecules caused multiple scattering of the particles with less energy. On the bottom of Fig. 5 we see a possible low energy muon decay. This particle came into the chamber with little energy (as compared to most muons that pass through our chamber) and decayed to produce an electron that made the track moving to the left of the picture.

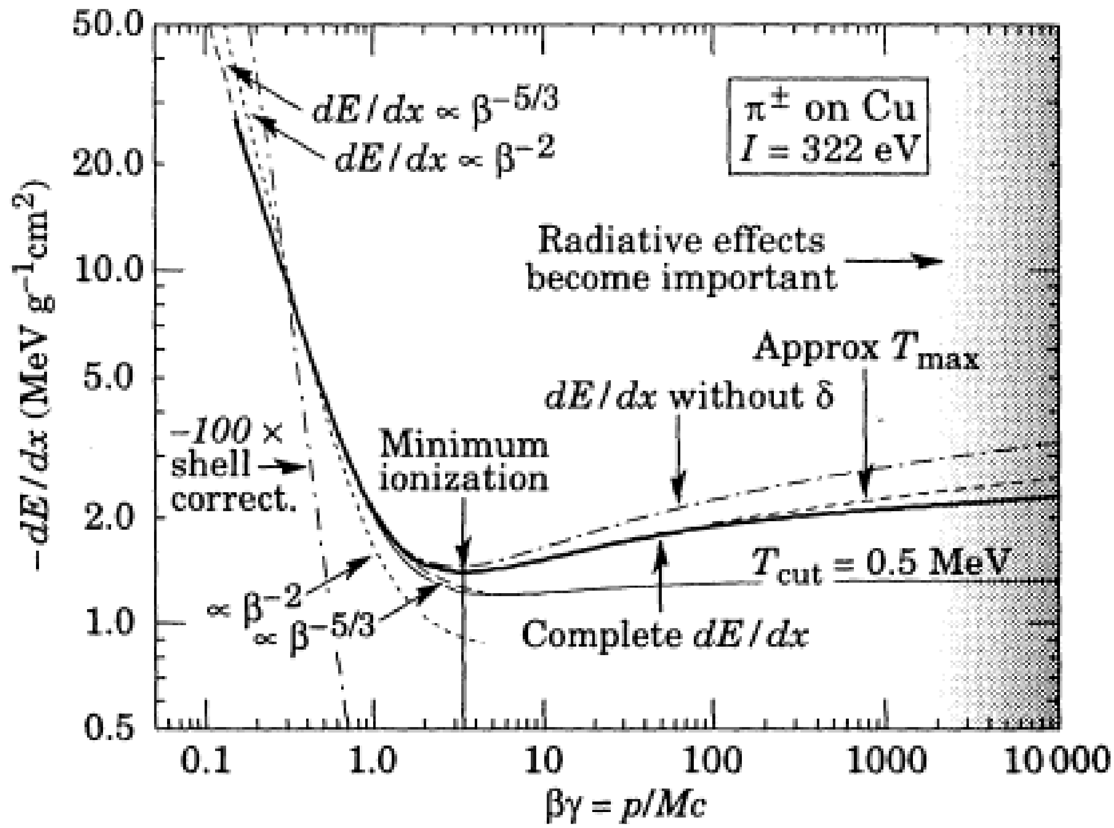

Figure 6. The Ionization chart for charged particles. This shows the energy of the particle as a function of brightness of the track [5].

To take the pictures of the tracks in our cloud chamber we used a 50 mm lens, with a depth of field of 5 cm, and an exposure time of 1/8 sec. The speed of the film was set at ISO125 with a F stop of F11. The type of film used was black and white for better resolution.

The tracks of certain particles and events can have a specific shape. Beta particles typically have tracks that are bright, twisted and bent.

We can determine which events we have witnessed directly from the track. A knock-on track has a T- like shape. A knock-on is when a charged particle hits an atom and an electron is knocked off of it and the electron and original particle move in different directions as illustrated in Fig. 7. A muon decay has a track that looks like it was moving straight but then turned abruptly.

Fig. 7 (a) represents a muon decay. What usually happens is the muon will decay into an electron, an electron anti-neutrino, and a muon neutrino. The neutrinos have no charge and are not detected by the cloud chamber but they are created at the same point.

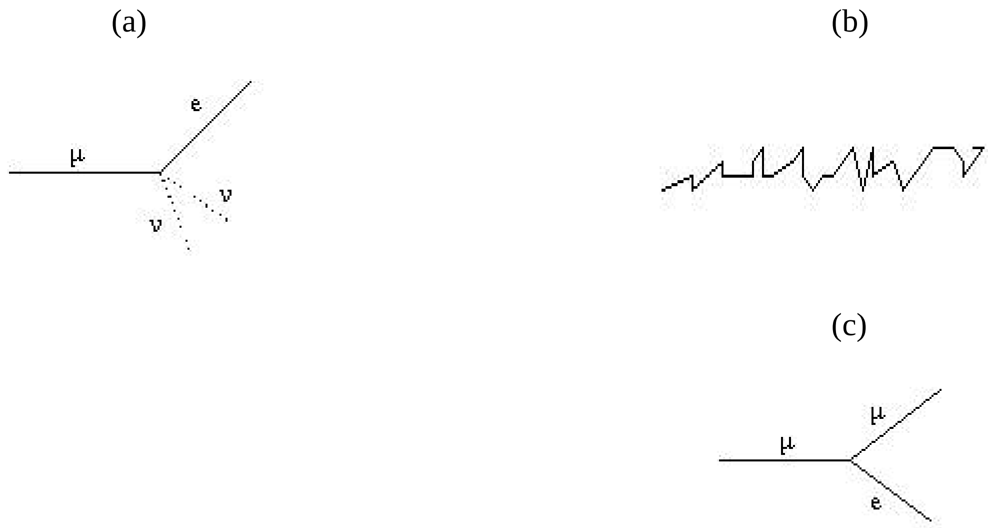

Figure 7. Drawings of: (a) muon decay, (b) electron scattering, and (c) knock-on.

What Are Cosmic Rays

A primary cosmic ray is usually a proton. This proton hits the atmosphere of the Earth and a strong nuclear interaction occurs, which among other things a pion is produced. The pion has a lifetime of about 0.28 ns and then decays into a muon. The muon has a lifetime of 1 μs before it decays, but usually we will see it pass through the cloud chamber before it decays. When the proton first hits the atmosphere of the Earth the particles formed have a distance of about ten kilometers to travel to make it to the surface of the Earth. The speed of light is about 30 cm/ns; so classical physics would tell us that the particles would never make it to the surface of the Earth. This is certainly not the case, and this is when special relativity comes in and tells us about time dilation. Because these particles are traveling at near the speed of light, time moves slower for the particles than on the Earth. Therefore they are able to complete their long journey from the top of the Earth's atmosphere.

Operation of the Cloud Chambers

We have had difficulties operating the larger cloud chamber, but we had few difficulties operating the small cloud chamber. The height of the larger chamber proved to be one problem. Also, the liquid ethanol precipitation was too thick to even be able to see tracks. Lowering the troughs helped that. A modest amount of ethanol on the bottom allowed us to see more precipitation due to the reflected light, but excessive ethanol on the bottom makes it difficult to see the tracks. In some cases we could not see the track formations because the ethanol precipitation was too thick.

The rate at which the ethanol vapor turns into a liquid is important and perhaps determined what the height of our chamber had to be. The temperature is responsible for the ethanol evaporating and condensing. We need to have a heating source to directly evaporate the ethanol in the troughs. This is why our larger cloud chamber did not work. We discovered this because we had the troughs too high above the bottom of the cloud chamber. It was visible that the ethanol precipitation was too dense. The particles traveling through the chamber were unable to be viewed due to the mass of ethanol liquid. This lead us to believe that there was not enough or perhaps not any super cooled vapor that could be used to allow tracks to form. By lowering the troughs, the ethanol was cooler. Therefore there was less ethanol evaporating, and then less ethanol on the bottom.

We believe the reason why there was so much ethanol liquid at the bottom of the chamber in the beginning was because the rate of which the ethanol vapor turned to a liquid. It was too fast for the vapor to make it all the way to the bottom without becoming a liquid. We had a great temperature gradient the only problem was our troughs were 28 cm from the bottom and they needed to be about 16.5 cm from the bottom, which was discovered experimentally. We made that adjustment and lowered the ceiling of the chamber, then with our good temperature gradient we had a super cooled vapor and we saw many tracks.

The small chamber had a good airtight seal that could block out strong wind currents that could disperse the tracks formed. The large cloud chamber through our different designs often had turbulence in the chamber until our final design. The airtight seal is not only important for controlling the turbulent air currents but it also keeps dust from getting inside the chamber. Because the supersaturation layer is sensitive to any irregularities, dust inside the chamber can lead to false tracks. Now with our more airtight chamber we do not have to worry so much about dust getting inside. Also, we experienced a problem of condensation along the outside of the chamber that can make it hard to see in the chamber. For that we plan to use a waxy substance with glycerol and apply it to the window.

The lighting arrangement did prove essential for seeing the tracks. For the large chamber we first had a piece of absorbent black felt on the bottom of the chamber. This black felt that we used was close to a wool like substance that reflected the light (when soaked with ethanol) and blinded the viewer from seeing most of the tracks. The droplets of ethanol would collect on the felt and reflect the light making it hard to see the precipitation and the tracks.

This led us to put black electrical tape on the bottom and we were able to see the precipitation of the ethanol. This is because the ethanol collects in a pool at the bottom, which does not reflect the light as well as the collection of ethanol droplets on the felt. Once a person can see the precipitation of ethanol then one can see the tracks forming.

We also noticed that the angle at which a person observes the tracks can affect how well one can see the tracks. Some good angles are looking directly behind the light source into the chamber. Also, one can look at an angle of thirty degrees in front of the light, which proved to be the best angle for viewing. The worst viewing angle is from the sides of the light source. We believe that is due to not enough light being reflected.

Results

The configuring of a sufficiently steep temperature gradient has lead to a greater supersaturated layer and an optimum rate (20 Hz) of track occurrence and observation. This involved numerous hours of configuring with key difficulties related to height and the temperature gradient.

Conclusions

Our experiences in constructing the cloud chambers have benefited our mentors and us. We have discovered many variables when constructing a cloud chamber: one of the hardest to control is the lighting of the chamber. There were times when we could not see all the tracks that were forming because of the lighting problem. As was mentioned before it was easier to look at the tracks while behind the light source or at an angle in front of the light. It was quite obvious that when we looked at the tracks from the side of the chamber it was hard to see most of the tracks. This information and the other data we have collected will aid our mentors in the construction of a cloud chamber to be used as a science exhibit. In our research we have learned important information concerning particle physics. By building this experiment equipment and handling it on a daily basis we have discovered it can be difficult, but were pleased in the end when it did finally work. There are many important properties that allow the chamber to work if any of these are not performing correctly than the chamber may not operate as well or at all. It is difficult to say which was the hardest property to control, but all in all we are glad to have learned much about the cloud chamber, and to have finally seen it working.

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